REVERSE BLOCKING CAPABILITY OF SYMMETRIC SCRS AT HIGH CURRENT AND HIGH VOLTAGE REVERSALS

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ABSTRACT

Symmetric thyristors with blocking voltages of 2.5 kV have been evaluated under high current conditions in circuits where a reverse voltage is applied to the SCR, caused by a load mismatch in the pulse forming network. The 50 mm diameter SCR was operated in a 45 mΩ PFN with a 12.5 mΩ load and a shorted load. The peak Current switched with the 12.5 mΩ load at 1.5 kV was 25.2 kA. The inverse voltage applied to the device was -740 V which was preceded by a voltage spike of -2.2 kV. This spike has a pulse width of 2.5 µs and a dv/dt, measured at the 10%-90% points of 875 V/µs. With the load shorted and an anode voltage 1.4 kV, 29.2 kA was switched with a pulse width of approximately 600 µs. The 2.8 µs reverse voltage spike under these conditions had a peak voltage of -2.5 kV, a dv/dt of 1.2 kV/µs and a recovery voltage of -1.1 kV. Data will also be presented on 3 SCRs operating in individual PFNs connected in parallel discharging into a common load. This simulates switches operating in the phases of a rotating machine. Data on the characterization and inverse voltage operation of new GE 100 mm SCRs will also be presented.

INTRODUCTION

There are applications in Army systems such as EM launchers where the switch is required to block voltage in the forward and reverse direction. The multiphase AC machine which provides energy for the railgun has individual switches in each phase. Each of these switches will switch energy into the system and then have to block voltage from another phase after it has discharged its energy. The switches have to be able to switch high peak, long pulse currents and block high voltages. Spark gaps or triggered vacuum gaps can operate in this regime but they have no reverse blocking capability, so a diode would have to place in series with these switches to block the reverse voltage. This adds complexity to the system, coupled with the fact that these type of switches have limited lifetime, pre-fire problems and jitter problems, have large ancillary requirements and are large in size and weight. This make for an inefficient switch.

Symmetric thyristors are capable of blocking voltage in both directions, switch long pulse high peak currents and have advantages over the other types of switches in every category but voltage hold off. Voltage hold-off is easily remedied by series stacking of devices. The overall

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size of the stack can be kept small with clever packaging techniques. In this study, SCRs were operated under simulated AC machine conditions, by operating them in a 45 mΩ or 21 mΩ PFN and switching them into a 12.5 mΩ load or a short circuit. The anti-parallel diodes and the clipper diodes were removed from the PFN so the network could be charged to a negative voltage. This charges the network to the opposite voltage forcing the device to block voltage in the reverse direct ion.

Two different SCRs ere tested under these condition. One was a 50 mm diameter Power Tech MT 1313, the characterization data for this SCR were published in an earlier conference proceedings[1]. The second device was a 100 mm GE SCR with a blocking voltage of 4.5 kV. Six switches were characterized in a 15 mΩ and 10 mΩ PFN and one was then operated under reverse conditions in the PFNs mentioned previously. The switches had an involute gate pattern and four of the six SCRs had there amplifying gates shorted. The characterization results will be presented later in the paper.

Test Set Up

The data was acquired on a Tektronix DSA 602A digitizing oscilloscope. Voltage was measured with a Tek P6015 1000:1 high voltage probe, the forward voltage drop was measured with a Tektronix P6001 10:1 probe and the current was measured with a Pearson CT 4000 1000:1 current transformer. In order not to saturate the amplifier while measuring the devices forward voltage drop a biased diode technique was used[1]. The rise and fall times are measured at the 26.%-70.1% points.

GE 6RT304HKW168 SCR CHARACTERIZATION DATA

The SCRs were 4.5 kV symmetric devices with a diameter of 100 mm. The devices were purchased with different amplifying gate structures in order to determine what effect this has on device operation. In a paper on another GE SCR that had a lower blocking voltage, different gate pattern and an amplifying gate, a failure mode was attributed to the amplifying gate[2]. The devices were characterized in the 15 mΩ PFN to 80% of their blocking voltage and then characterized in the 10 mΩ PFN to find the upper current limit of the SCRs, with the goal being 200 kA. It was felt that the shorted amplifying gate devices had a chance to achieve this goal, because of the better turn-on characteristics of the shorted gate structure, but neither type of device was able to do so. The amplifying gate SCR actually reached a higher peak current than the shorted device contrary to the author's belief. So the peak current of the device is limited by the device active area.

This device has the involve gate structure. The involute design is supposed to improve the devices turn-on characteristics, such as the di/dt and rise-time, by turning on more device active area simultaneously. Figure 1 are the current and voltage waveforms of the SCR in the 10 mΩ PFN. The anode voltage was 3.3 kV with a peak current of 164 kA in a 490 μs pulse (FWHM). The rise-time of the current was 58 μs, a fall-time of 112 μs and a di/dt of 826 A/μs. the forward voltage drop went from 47 V measured at the 100 μs point of the current pulse, to 26 V at the 200 μs point at which time it began to increase. It increased up to 33 V, but the waveform showed a discontinuity at this point. When the forward drop increase after falling it

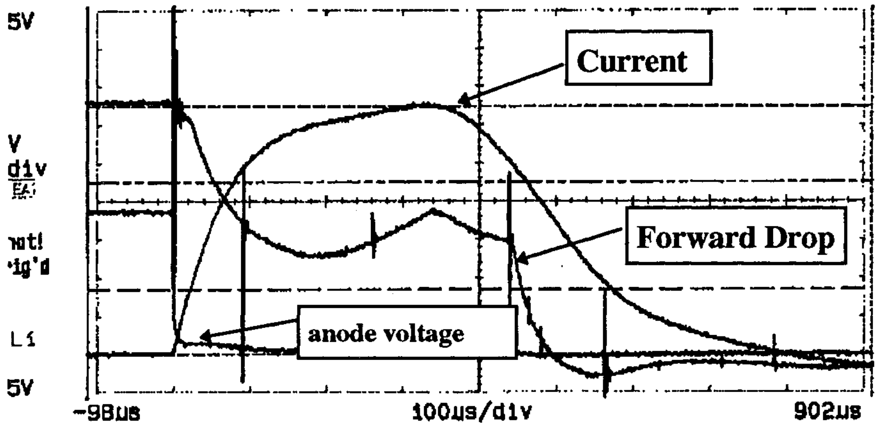
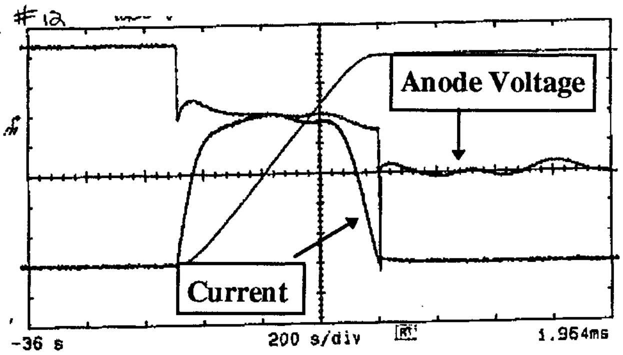


Figure 1. Characterization waveforms of GE SCR.

is a sign of heating in the device. When there is this discontinuity is a sign of extreme heating and device failure is imminent or it fails at this point which this one did. This heating is caused by a low resistivity channel forming in the device which causes more current to flow in this region increasing he temperature lowering the resistivity further. This phenomena occurs until device failure. All of the devices failed like this except that this device achieved the highest peak value.

INVERSE OPERATION

The anode voltage in these tests did not exceed 1.5 kV so the total voltage swing would not to exceed the voltage ratings of the capacitors which are 4.5 kV. The first device to be operated under the reverse blocking conditions was the Power Tech MT 1313 50 mm SCR. Figure 2 are the voltage and current waveforms of the SCR at 1200 V in a 45 mΩ PFN with a 12.5 mΩ load. Figure 2a is the current and voltage waveforms on a 200 µs/div time scale and figure 2b is a window of the inverse voltage spike at 10 µs/div. The voltage waveform has a fall-time of 1.53 µs. At the end of the current pulse, there is a voltage spike of -1.8 kV across the device after which the voltage settles to -620 V, with no reverse breakdown or current flow. The spike is the typical diode reverse recovery. The pulse width of the spike is 2.46 µs, with a dv/dt of -744 V/us. The peak current of the shot was 20.8 kA with a rise-time of 102 µs. The pulse width (FWHM) was 594 µs. The peak inverse current was -1200 A. This also showed the turn-off characteristics of a diode. For the shorted load test at this voltage the inverse voltage spike increased to -2.66 kV form -1.86 kV, and the spike pulse width was 2.66 µs. The dv/dt of this spike was -1.24 kV/µs. The impedance of the PFN was lowered to 21 mΩ by paralleling it with another 45 mΩ PFN to increase the discharge current. The peak current was 51.6 kA with a -2.4 kA inverse current, at an anode voltage of 1.24 kV. The inverse voltage spike was -2.18 kV with a pulse width of 3.3 µs and dv/dt of -1.44 kV/µs. The results of the inverse voltage testing for this SCR are summarized in Table 1.



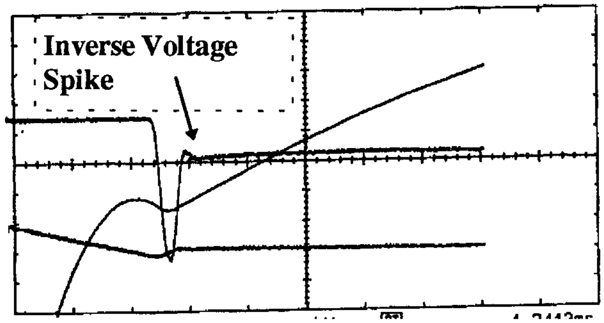


Figure 2. Top graph is Figure 2a which is anode voltage and circuit current.
Lower graph is Figure 2b which has inverse voltage spike.

Table I

PFN,mΩ	Load,mΩ	Voltage, kV	Voltage, spike, kV	Inverse voltage, V	Pulse Width, Spike, μs	dv/dt, V/μs	Peak Current,kA	Inverse Current, kA
45	12.5	1.24	-1.86	-620	2.46	-744	20.8	-1.2
45	short	1.2	-2.66	-950	2.7	-1237	25.2	-0.8
21	short	1.24	-2.16	-950	3.31	-1438	50.8	-2.4

PARALLEL PFN OPERATION

To further simulate an AC machine, 3 50 mm SCRs were each palced in a 45 mΩ PFN that were each connected in parallel to a common 15 mΩ load. In this configuration the individual SCRs coulc be triggered in a sequence to shape the totla current puilse or could be triggered so that there is delay between each individual current pulse. The following figures are examples of this.

Figure 3 is the current waveforms of the individual currents and the total current which is the summation of the three current pulses. The peak current of the total pulse is 4 kA, it has a rise time of 31 μs and a pulse width of 1.1 ms. The peak current of the first SCR is kA and a rise of μs and a pulse width of 368 μs . The second SCR's peak current is 4 kA with a pulse width of 382 μs, and the last SCR's peak current is 3.8kA with a fall time of 39 μs and a pulse width of 380 μs. The three pulse widths add up to approximately the total current'ts pulse width. This

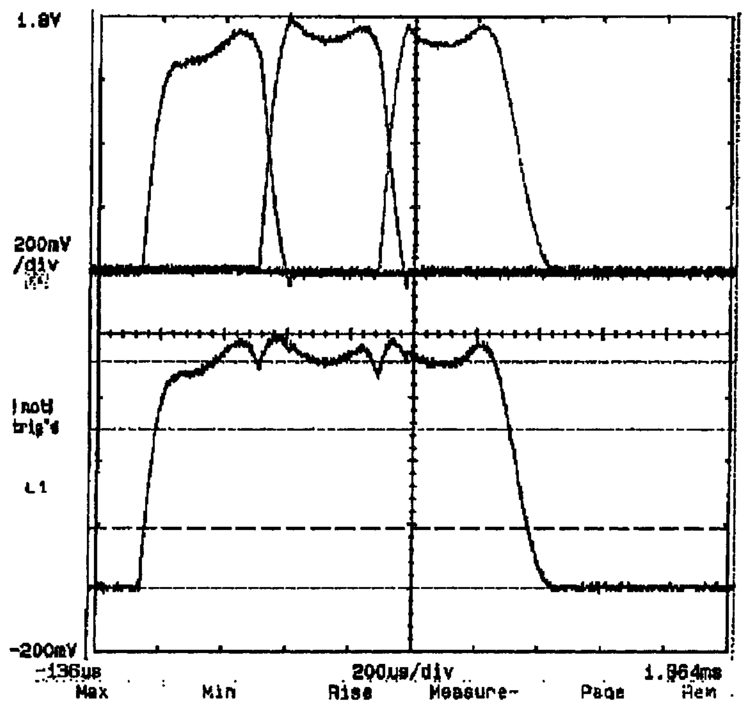


Figure 3. Top waveforms are individual curreet pulses of the 3 SCRs, veritcal scale 1 kA/div. Bottom waveform is total current formed by summation of 3 SCR currents, veritcal scale 1 kA/div.

shows that the SCRs can be used to shape current pulses with no adverse effects such as reverse breakdown. Figure 4 is the 3 SCRs being triggered sequentially but with a time delay of 500 µs between each individual current pulse. Each current pulse has a peak current of about 11 kA. The important data that this figure dispalys is the there is no reverse breakdown in the devices that are in their blocking state while the other devcie is discharging it's PFN. Voltage data was not displayed on these graphs because there were not enough data channels available for all information. If there was reverse breakdown it would be seen by negative current flow in the the individual current traces.

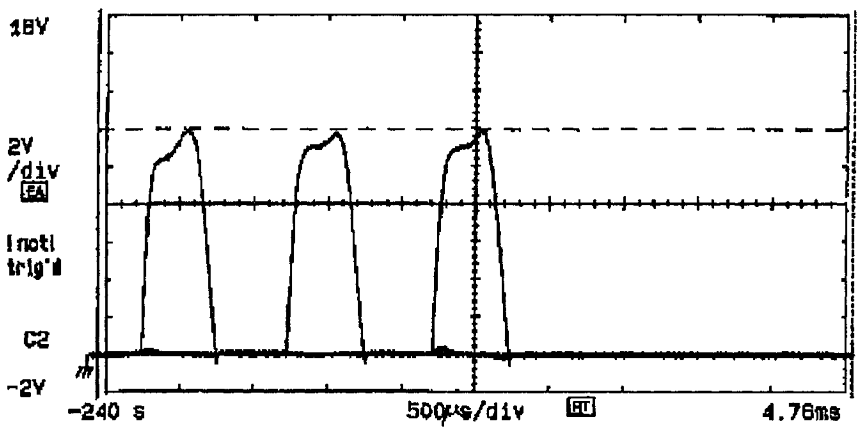


Figure 4. Three SCRs being trigged sequentially.

GE SCRS

The 100 mm diameter GE SCR was tested for inverse voltage capability in the 15 mΩ PFN with no load and no protective diodes in the circuit. The switch was only tested up to 1.5 kV for the same reasons as the 50 mm SCR. Figure 5a show the anode voltage of 1.5 kV, switching to the on state in a fall-time of 2.4 μs, and blocking a turn-off voltage spike of -2.66 kV. The lower waveform is the current pulse which has a peak value of 91 kA, a rise-time of 57.27 μs and a pulse width of 584 μs. Figure 5b is an expanded view of the voltage spike. The spike had a pulse width of 3 μs, a fall-time of 1.48 μs and a dv/dt of 902 V/μs.

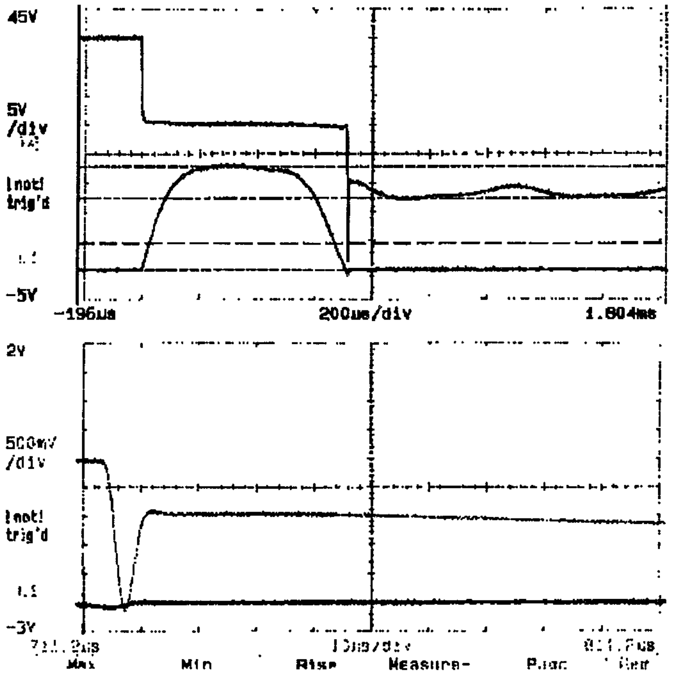


Figure 5. Top graph is figure 5a of anode voltage(topmost waveform) , 500 V/div, and current 25 kA/div. Bottom graph is Figure 5b, showing the inverse voltage spike, 500 V/div.

CONCLUSION

The switches handled these inverse voltage tests successfully proving they could be operated under conditions where they will be required to block voltage in both directions after discharging large peak currents. The devices were able to withstand dv/dts greater than there ratings without breaking down. Tests were run using SCRs to shape current pulses, as they might do in a real EM gun system, with no adverse effects. These switches also triggered sequentially with a large delay between each pulse with no reverse breakdown.

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